Chapter 7. *Mega Borg* Oil Spill Studies; Effects on Shrimp

James M. Nance
National Marine Fisheries Service
Galveston Laboratory
Galveston, Texas

Introduction

Shrimp Fishery General Background

Nine shrimp species contribute to the fishery in the Gulf of Mexico. However, brown, white, and pink shrimp of the genus *Penaeus* comprise over 95 percent of the commercial harvest and are the only species, besides royal red shrimp (*Hymenopenaeus robustus*), currently included in a federal fishery management plan (FMP). These shrimp species are generally found in all continental shelf waters in the Gulf of Mexico inside 60 fathoms (fm). The greatest portion of the reported offshore catch of brown shrimp (*Penaeus aztecus*) is taken at depths of 11-20 fm, white shrimp (*P. setiferus*) in 10 fm or less, and pink shrimp (*P. duorarum*) in 11-15 fm. The largest densities of brown shrimp occur off the Texas/Louisiana coast; the largest concentrations of white shrimp occur off the Louisiana coast; and the greatest densities of pink shrimp occur off the southwest coast of Florida.

Brown, white, and pink shrimp all have a similar life cycle in which spawning occurs offshore. However, the time that recruits enter the fishery differ for the three species. Eggs generally hatch into planktonic larvae after 10-12 hours. During the next 12-15 days, these larvae metamorphose through additional planktonic stages into postlarvae as they move from offshore waters towards inshore areas. Upon entering the estuaries, these postlarvae become benthic and develop quickly into juvenile shrimp. These small shrimp have a voracious appetite and their diet includes diatoms, polychaete worms, and small crustaceans. Any natural or man-induced changes in estuarine habitat can alter shrimp survival at this stage in their life cycle. After a few weeks in the estuaries, young subadult shrimp begin the migration process back out into offshore areas. The average life span of these three species is thought to be about 12 months, although some live for 2-3 years. Sexual maturity is usually attained between ages 5-8 months, depending on the species.

Brown shrimp begin entering estuaries in February and continue through April. However, depending on water temperature and environmental conditions, immigration into the bay during some years can occur through July. Several "waves" of postlarvae may enter an estuary, but peak recruitment occurs in March and April, with a small peak sometimes in September. The postlarvae use the estuary as a nursery and eventually migrate back into the offshore waters as subadults. While in the bays, juvenile shrimp are harvested by recreational and commercial fishing during the spring and summer months. Emigration of juveniles to offshore waters begins in May and ends in August, with peak emigration occurring in May, June, and, to some extent, July.

White shrimp postlarvae begin entering estuaries from May to November, with peaks in June and September. These postlarvae use the estuaries as nurseries during the summer and fall and grow to a size of about 120 mm total length in the bays, where they are harvested by recreational and commercial fisherman during late summer. White shrimp emigration is a function of size and environmental conditions within given bay systems. Usually the shrimp begin emigrating in September and end in December.

Pink shrimp postlarvae begin entering estuaries in the summer with peak recruitment occurring in the fall. They spend two to six months in nursery areas. Pink shrimp attain a size of 95 to 100 mm total length before emigrating from estuarine nursery areas to offshore waters. However, size is probably seasonally and areally-dependent. Emigration occurs year-round with peaks in the spring and fall.

The harvest is usually conducted year-round with otter trawls. However, traps, butterfly nets, cast nets, and seines are also employed in some areas. As noted above, peak seasonal fishing activity is species-specific. Average annual commercial shrimp whole weight catch for all species combined during the last eleven years (1980-1990) is 108,213 metric tons (MT), with a value of $417 million. The greatest harvest occurred in 1986 (137,949 MT; $565 million), while the lowest catch was in 1980 (86,719 MT; $321 million). On the average brown shrimp accounted for 58 percent of the harvest, with white shrimp at the 31 percent level and pink shrimp only making up eight percent of the total catch. The other six commercially harvested shrimp species combined accounted for only three percent of the total. Peak brown shrimp harvest occurred in 1990 (75,518 MT; $250 million), white shrimp in 1986 (49,432 MT; $221 million), and pink shrimp in 1981 (13,885 MT; $48 million). The peak season for the other six shrimp species combined was 1986 (8,096 MT; $8 million).

Mega Borg Spill

On Friday night, 8 June 1990, an explosion occurred onboard the 885-foot Norwegian supertanker *Mega Borg* while transferring the petroleum cargo to smaller and shallower draft vessels for transport into shallow water ports. At the time of the explosion the *Mega Borg* was 65 nautical miles (nm) offshore from Galveston, Texas, and contained an estimated one million barrels (bbl) of light Angolan crude oil. During the next week, approximately 121,000 bbl of oil escaped into the Gulf of Mexico.

When the *Mega Borg* oil spill occurred, brown shrimp were near the end of their spring spawning cycle, and most brown postlarvae had entered the Galveston Bay system to grow into juveniles and subadults. However, due to flood conditions in the Trinity River that spring, the Galveston Bay system had unusually low salinities, which could have initiated an early migration of brown shrimp subadults into the Gulf of Mexico. Thus, large concentrations of benthic subadults and adults could have been present in the <20 fm zone during the spill and the weeks that followed.

White shrimp were in the early to mid-stages of their spring spawning cycle when the spill occurred, and postlarvae in the nearshore area probably were quite high in numbers, since the peak migration into the bays usually occurs in the June through August period. Most of the white shrimp postlarvae were probably offshore and had not already entered the Galveston Bay system when the spill occurred. Thus, large concentrations of pelagic postlarvae and a few benthic adults could have been present in the <20 fm zone during the spill and the weeks that followed. Since white shrimp are more tolerant of lower salinities than brown shrimp, any juvenile and subadult white shrimp within the Galveston Bay system were able to remain there despite the flood conditions.

The National Marine Fisheries Service (NMFS) presently collects only fishery-dependent data on the benthic subadult and adult shrimp stocks in the area. Thus, the analysis included only the potential impacts of the oil spill on the adult brown shrimp emigrating into the offshore waters and not the postlarval white shrimp present in the area. The NMFS shrimp catch data are summarized monthly by statistical subarea and 5 fm depth zones (Fig. 7-1). These "location cells" (month/area/depth) are the smallest units by which the shrimp data can be examined during analysis.

Materials And Methods

The potential effects of the *Mega Borg* oil spill on the brown shrimp fishery along the upper Texas coast was determined using the following methodology. First, a Gulf of Mexico brown shrimp stock model was developed that depicted both the abundance and the movement of brown shrimp from the inshore to the offshore areas. The model incorporated life history information such as recruitment abundance in the bays, offshore migration rates, natural mortality rates, growth rates and fishing mortality rates. For the *Mega Borg* impact analysis, only the area 18-21 portion of the model was used. Thus, the impact model had only three compartments (i.e., inshore, 0-10 fm, and >10 fm). No effect for the inshore area was determined. Only the nearshore and offshore areas were considered during the analysis.

As can be seen in Figure 7-2, statistical area 18 occurs between 95°W and 94°W longitudes. The 20 fm depth contour occurs near where the *Mega Borg* was anchored and runs perpendicular to the longitude lines. The 10 fm depth contour also runs perpendicular to the longitude lines and is near 29°N latitude. It appeared from the aerial surveys that the surface oil moved north from the *Mega Borg* site and stayed between 94°00'W and 94°30'W longitude. From a digitization of the surface oil data, at a maximum, only about one-half of this area was covered by the oil. Thus, only about one-quarter of statistical area 18, from the 20 fm depth zones to the beach was affected by the oil (zone of impact).

To determine the percentage of the brown shrimp population in the zone of impact, the following calculations were made. Monthly average catch per unit of effort (CPUE) data were calculated from pre-closure years (1970-1979). CPUE was calculated by statistical subareas and three depth zone intervals (0-10, 11-20, and >20 fm) for the months of June, July, and August. These pre-closure years were used since from 1981 to the present no fishing occurs in Texas waters from around 15 May through 15 July and abundance can not be assessed. It was assumed that the distribution of shrimp abundance in 1990 was similar to the average abundance

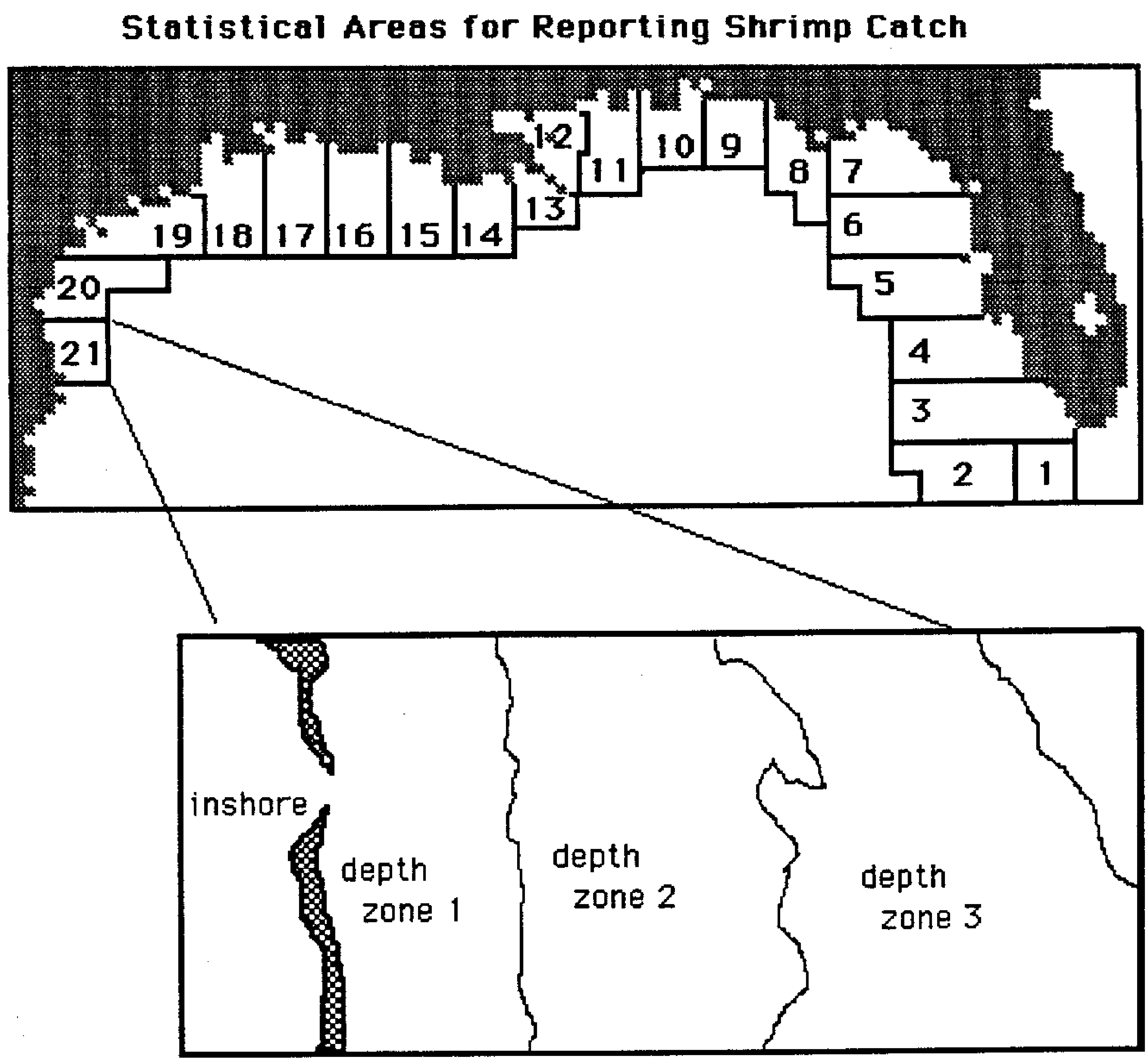

FIGURE 7-1. Distribution of statistical subareas and depth zones within the Gulf of Mexico.

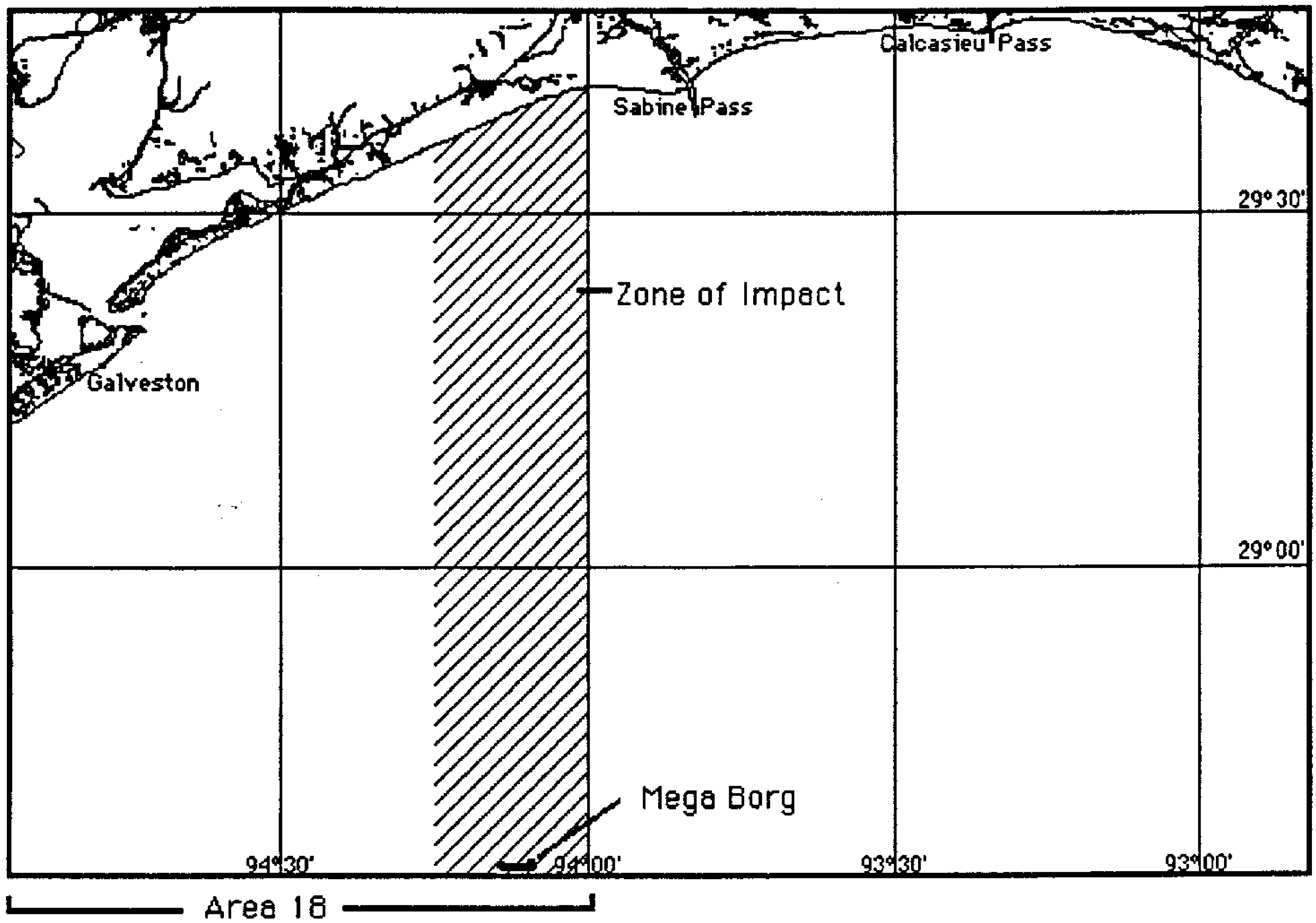

FIGURE 7-2. Detail of statistical subarea 18, with reference to the zone of impact from the *Mega Borg* oil spill.

distribution from 1970 through 1979. It was then assumed that shrimp in each statistical area/depth zone combination were equally distributed throughout that location cell. Percentages of total monthly population in the zone of impact were determined by calculation of the percentage of the monthly population in each of the three zones in subareas 18 and then dividing these values by four.

Once the model was developed and the percentage of the population affected was determined, the concentration of oil within the water column from sites near the *Mega Borg* was determined to see the levels of oil that the shrimp in the area were exposed to following the spill. Next, a bioassay study was undertaken to determine the LD_{50} for Angola crude oil, dispersant and oil-dispersant mixtures on penaeid shrimp or the selected surrogate species. Toxicity data from the bioassay results and data from offshore oil concentration samples were integrated to establish zones of effect. These zones were perpendicular to the longitude lines. They were based on the average toxicity at the sample sites.

Finally, zones of effect were interlaced into the population model to assess the potential impacts of the oil spill on brown shrimp off the Texas coast. This was accomplished through the following calculations with the data. The percentage of the population affected by oil in a given month was removed from the total brown shrimp population, and the remaining population, based on the toxicity effects, was replaced into the total population (i.e., if there was a 50 percent death rate for a given zone, then only 50 percent of the removed population would be placed back into the total population).

Brown Shrimp Model

The Gulf of Mexico was divided into three geographic areas during model development and analysis using the statistical subareas established for summarization of shrimp catch and effort data (Fig. 7-1). These geographic regions included West Gulf (subareas 18-21), Northwest Gulf (subareas 11-17), and Northeast Gulf (subareas 7-10). Although it may have been desirable to break the Gulf into units by individual states, functionally these three units represented the best biological partitions. Subareas 18-21 were kept together because an offshore shrimp closure already exists in this region. Subarea 11 was placed with subareas 12-17 due to the fact that it, like the other six subareas, represented a major brown shrimp harvesting area. Subareas 7-10 delineated the area of low brown shrimp harvest.

Each of these geographic locations were subdivided into three depth zones. The first zone included all the inshore areas; bays and estuaries. The second zone (nearshore) comprised the area from the beach out to a depth of 10 fm. The third zone (offshore) contained the area with a water depth greater than 10 fm.

The basic functional component of the model had a very similar design/structure to the GBFSM model developed by Grant *et al.* (1981). However, our model was based on an age-structured population, and size considerations were implicitly modeled within the age structure. There was a compartment for each age class (0 through 17 months, in half-month intervals), geographic area (West Gulf, areas 18-21; Northwest Gulf, areas 11-17; and Northeast Gulf, areas 7-10), and depth zone (inshore, beach to 10 fm, and greater than 10 fm) combination. The functional concept behind the model was as follows: 1) during each bimonthly time interval, new shrimp moved into an age compartment box; 2) instantaneously, natural and fishing mortality were applied to these shrimp; and 3) all remaining shrimp increased in age and moved into the next age compartment box as new shrimp. Although this overall functional model concept was simple, the calculations involved to estimate number of new recruits, fishing (F) and natural (M) mortality rates, and perpendicular to shore migration rates (P) were complex and required assumptions when the necessary data inputs were not available for analysis.

Biological Data Input

Five basic data requirements were necessary for model development: 1) monthly recruitment values of age 0 shrimp entering into the fishery; 2) initial population size estimates for each age class at the beginning of the simulation; 3) monthly instantaneous rate of natural mortality (M); and 4) monthly instantaneous rate of fishing mortality (F), and 5) perpendicular to shore migration rates (P) of various bimonthly cohorts from inshore bays to offshore waters.

Monthly instantaneous rate of natural mortality (M) for brown shrimp is currently estimated to be between 0.20 and 0.35, with the median equal to 0.275 (Nichols, 1984). Since there is little justification for narrowing the range, the median value was considered the best estimate of the instantaneous rate of natural mortality and was used in the simulation model during closure analysis.

Virtual population analysis (VPA), based on catch statistics from the brown shrimp fishery (1960-1989), was used to produce estimates of both the monthly fishing mortality rates and the number of shrimp in each monthly age class (age 0 through age 17), for the selected geographic location (Nance, 1989). In this analysis, age 0 shrimp have a minimum size of 45 mm tail length. Thus, initial population values for each age class, monthly recruitment levels of new shrimp entering into the fishery, and monthly fishing mortality rates (F) by age class were all obtained from this VPA procedure and are used as data input in the simulation model. VPA data from April 1988 through March 1989 were selected for input into the model because they reflect the most recent trends in the fishery without a 200 mile closure off Texas. These data represent the baseline values for comparative purposes for all closure simulations.

CPUE by size data, from fishery dependent statistics during the 1986 through 1988 time frame, were summarized by month, geographic location, and depth. A CPUE by age table was then constructed for each month, area, and depth combination. Percentage of total brown shrimp population within each depth zone was calculated for each age class and month. These data were then utilized to partition the initial age class population size groups into their various depth components, and also to estimate migration rates to offshore waters using the following technique: 1) inshore and offshore population estimates by depth zone data were plotted for each monthly cohort with percent composition as the dependent variable (y-axis) and age as the independent variable (x-axis); and 2) regression analysis was used to estimate the slope of the line (linear or curvilinear) through the data. The line through the inshore data represented the migration rates of shrimp leaving the inshore waters, while the line through the offshore data represented the migration rate of shrimp entering the offshore waters. Regression was not necessary to calculate values for the nearshore area, since it was simply the fraction of the population not in the other two areas. Migration rates were calculated for the April, May, June, July, and August cohorts from each of the geographic locations. August migration rates were used for the September through March cohorts in each location.

The biological data inputs allowed the model to simulate the number of shrimp harvested by age class. Using conversions obtained from growth equations (Parrack, 1981), shrimp were grouped into standard size categories and yield in pounds was calculated for the various harvest levels. Total Gulf of Mexico yields were obtained by adding the yields from each of the three geographic locations.

Revenue Data Input

Value of the harvested shrimp was established for each regional area by determining the average monthly price-per-pound for each of the size categories. These monthly prices were obtained for the 1986 through 1988 period and then standardized into 1989 dollar values. These values were averaged to obtain the mean annual price per pound for each size category in each regional area. These price-per-pound estimates allowed revenue curves to be developed for each of the closure options.

Model Verification

Baseline simulations were performed to generate catch and revenues for the Texas area. Output from baseline simulations were compared with Gulf of Mexico catch statistics to check for discrepancies between actual landings revenues and those generated by the simulation model for the 1988 biological year (April 1988-March 1989). Major differences among yields would reflect the degree of uncertainty regarding model output and would thus invalidate the model. On the contrary, small differences would tend to validate the model.

Field Sampling of Oil Concentrations

Water and sediments samples from near the *Mega Borg* spill area were collected and analyzed by the Geochemical and Environmental Research Group (GERG) at Texas A & M University. Four reports were sent to the NMFS Galveston Laboratory with the results of their analysis. These reports included: 1) Technical Report 91-013, The *Mega Borg* Oil Spill - Preliminary Assessment of Sediment Contamination; 2) Technical Report 90-094, *Mega Borg* Oil Spill - June 1990 - Analysis of Selected Oil, Tar, and Water Samples; 3) Technical Report 91-015, *Mega Borg* Oil Spill - Water Sample Analyses for NOAA; and 4) Technical Report 90-097, *Mega Borg* Oil Spill - Water Analysis Dispersant Effectiveness Study. Copies of these four reports are available from the NOAA Damage Assessment Center in Rockville, Maryland, 20852. Analyses for a total of 12 sediment samples and 55 water samples are contained in the reports.

Total petroleum hydrocarbon concentration at each offshore water collection station was estimated by the U.S. Environmental Protection Agency, Environmental Research Laboratory in Gulf Breeze, Florida, from the data presented in the reports. Total petroleum hydrocarbon concentration at each station was assumed to equal the sum of total aliphatics and total aromatics reported at the station. These hydrocarbon concentrations were compared to the bioassay concentrations to determine the toxicity of the hydrocarbon levels found at the offshore sites.

Bioassay Study

The bioassay study was conducted by the U.S. Environmental Protection Agency, Environmental Research Laboratory in Gulf Breeze, Florida. The methodology used during the study can be found in the report titled, Acute and Chronic Toxicity of Oil Samples from the *Mega Borg* Tanker to Mysid (*Mysidopsis bahia*) and Penaeid (*Penaeus setiferus*) Shrimp (Appendix 6).

RESULTS

Brown Shrimp Model Results

The model seems to provide an accurate biological simulation of the brown shrimp fishery (pounds and revenue) along the Texas coast. The total Texas monthly landings for the simulated baseline mimicked the actual landings trend, with a simulated landings peak in July of 8.2 million pounds and a low of 0.3 million pounds in March (Fig. 7-3). In most cases the simulated landings compared extremely well to the actual. The greatest difference between simulated and actual catch values was about 16 percent on a monthly basis. Actual Texas landings for this biological year were 31.3 million pounds, whereas the simulated landings were 30.8 million pounds; a 2 percent difference. Revenue for the simulated baseline data followed the actual revenue values and ranged from a low of $1.4 million in March to a high of $24.5 million in July (Fig. 7-4). The greatest difference between simulated and actual values was approximately 20 percent on a monthly basis. Total revenue for the actual baseline was $104.9 million, whereas, the simulation was $105.5 million; a one percent difference.

It was determined from data plots of aerial surveys conducted by NOAA during the oil spill that the oil slick in June covered about 25 percent of the ≤20 fm depth zone in statistical subarea 18 at its greatest distribution. It was assumed that the oil in the water column had the same distribution as the oil on the surface. It was also assumed for analysis that the oil stayed in this same distribution in July and August. Abundance of brown shrimp in statistical subarea 18 was calculated by depth zone for June, July, and August and the abundance of shrimp potentially affected by the oil was determined. Approximately 13.45 percent of the brown shrimp population along the Texas coast in the ≤10 fm depth zone and 2.62 percent of the population in the >10 fm depth zone was in the area affected by the oil in June; 9.66 percent of the shrimp population in the ≤10 fm depth zone and 5.55 percent of the population in the >10 fm depth zone were in the area affected by the oil in July; and 18.92 percent of the brown shrimp population in the ≤10 fm depth zone and 7.93 percent of the population in the >10 fm depth zone was in the area affected by the oil in August.

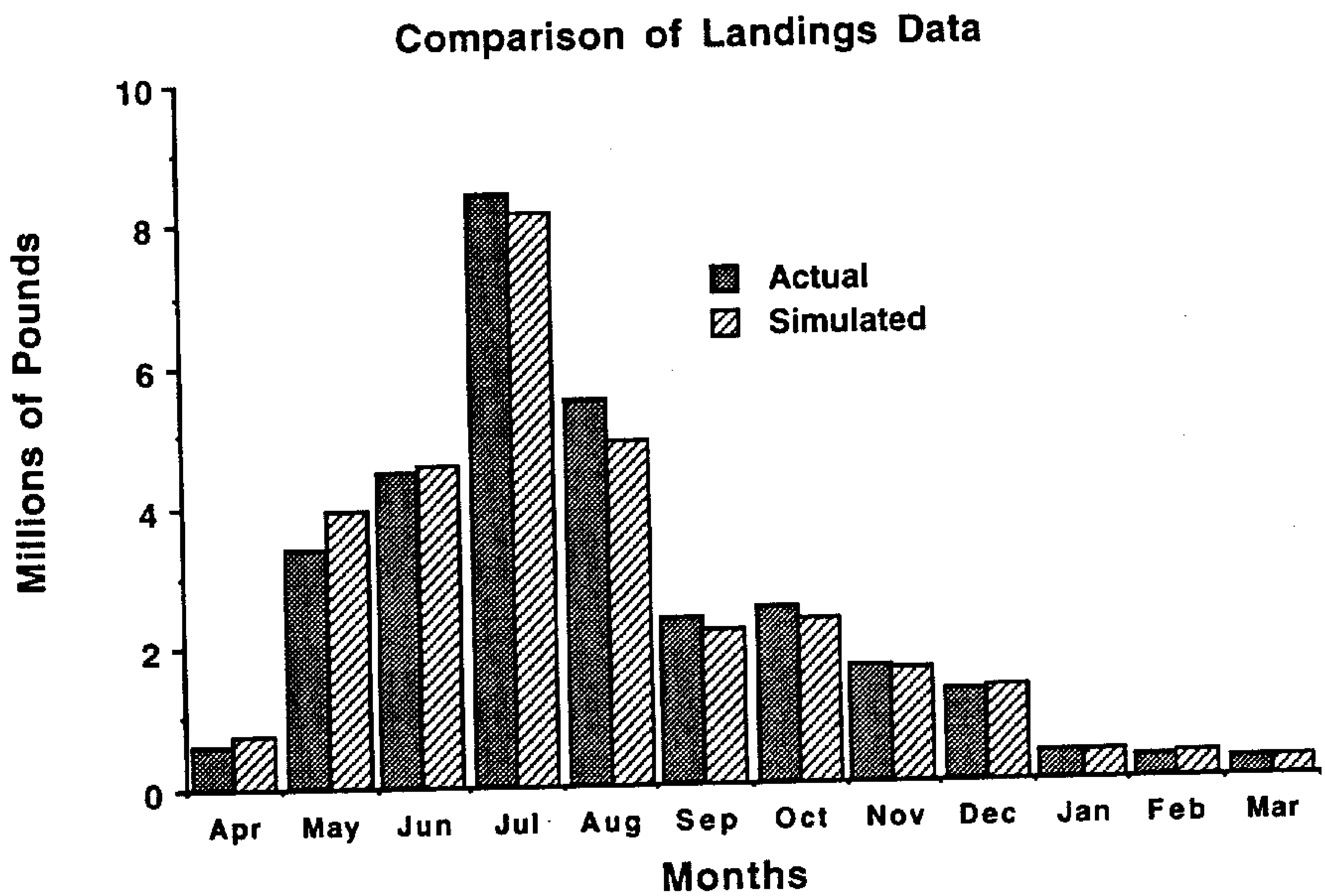

FIGURE 7-3. Model verification analysis for brown shrimp pounds caught in the fishery off Texas.

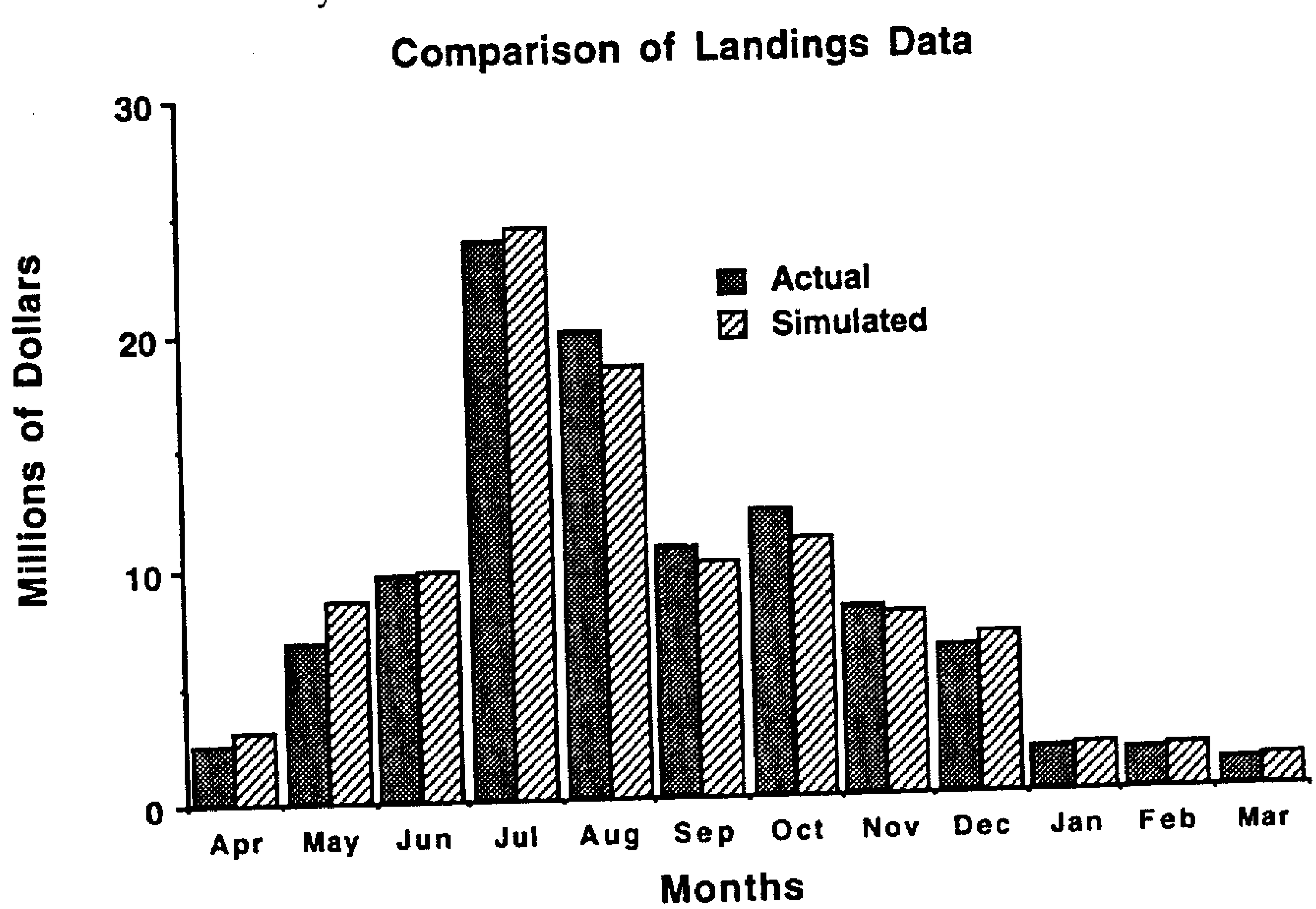

FIGURE 7-4. Model verification analysis for brown shrimp revenue in the fishery off Texas.

Field Sampling of Oil Concentrations

Hydrocarbon concentrations found at the offshore stations around the *Mega Borg* are listed in the reports from the GERG at Texas A & M University. Estimated total hydrocarbon concentrations found at the sediment collection stations ranged from 1.38 μg/g to 7.42 μg/g, while concentrations at the water column sampling sites ranged from 0.69 μg/l to 27.39 μg/l. Evaluation of chromatograms and analytical data suggested that sediments from the area contained primarily biogenic hydrocarbons. Only one station had elevated hydrocarbon levels. However, these values were only three to five times higher than the concentrations measured at the other stations. Evaluation of the water samples from the area showed only very low concentration levels of hydrocarbons were present in the water column.

Bioassay Study

Results of the bioassay study can be found in the report titled, Acute and Chronic Toxicity of Oil Samples from the *Mega Borg* Tanker to Mysid (*Mysidopsis bahia*) and Penaeid (*Penaeus setiferus*) Shrimp (Appendix 6). The main conclusion from the study was that the concentrations of hydrocarbons measured at the water sampled field sites tended to be three orders of magnitude lower than the petroleum hydrocarbon concentrations causing toxic responses (both acute and chronic) in mysid and white shrimp. Based on this result, the toxicity within the zone of impact was determined to be zero (i.e., no zones of effect within the zone of impact).

DISCUSSION

This brown shrimp fishery model seems to represent an accurate simulation of the present conditions found along the Texas coast. Although many assumptions were made during the development of the model, each was generated with the best available information. We feel comfortable with the model because the simulation of baseline conditions for the 1988-1989 period generate approximately the same pounds and revenue observed in the actual fishery. This model will be useful if a brown shrimp impact analysis is again necessary in the future.

Based on the bioassay analysis and field sampling results, there were no detected effects to the brown shrimp population along the Texas coast from the *Mega Borg* oil spill. This conclusion is supported by the annual landings data from shrimp caught off the Texas coast (Fig. 7-5). As can be seen, no decrease in catch was observed during the 1990 season.

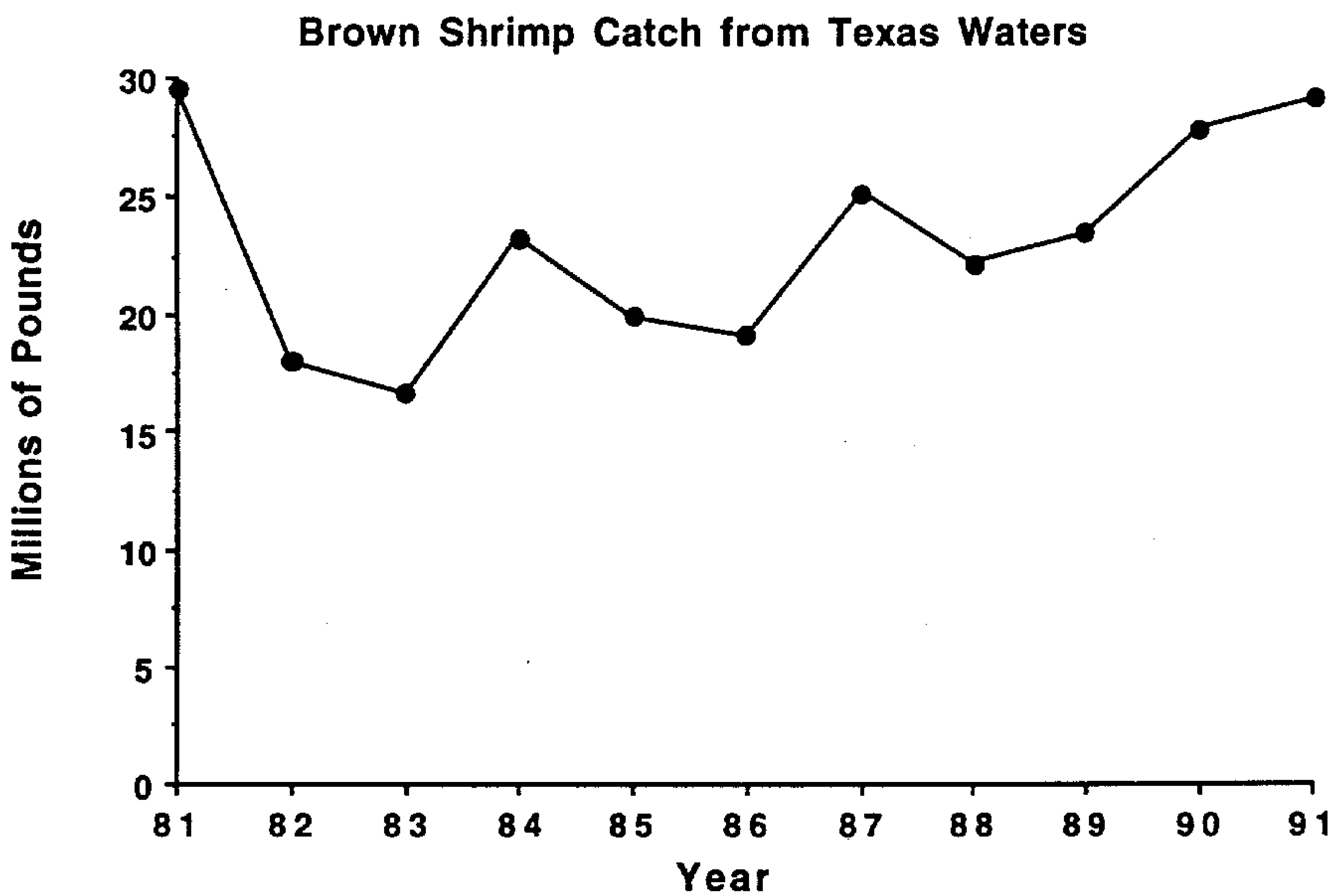

FIGURE 7-5. Brown shrimp landings from Texas for the past eleven years.

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